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16. ABSTRACT

This paper is primarily a summary of two previously published detailed reports on the health effects of land treatment (Kowal 1982, 1985), and the reader is encouraged to seek there the supporting data and arguments for the generalizations made here. In those reports the types and levels commonly found in municipal wastewater and the efficiency of preapplication treatment (usually stabilization pond) are briefly reviewed for each agent of concern. A discussion of the levels, behavior, and survival of the agent in the medium or route of potential human exposure, i.e. aerosols, surface soil and plants, subsurface soil and groundwater, and animals, follows as appropriate. For the pathogens, infective dose, risk of infection, and epidemiology are then briefly reviewed. Finally, conclusions and research needs are presented.

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HEALTH CONSIDERATIONS IN APPLYING MINIMUM TREATED WASTEWATER TO LAND

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Introduction

There are three types of land treatment systems in general use: slow rate (or "irrigation"), rapid infiltration (or "infiltration-percolation"), and overland flow. Slow rate is the most commonly used land treatment system. Wastewater, usually pretreated by some process, is applied by sprinklers, surface flooding, or ridge-and-furrow irrigation, at a rate of 2-20 feet (0.6-6 m) per year. Soils are usually medium to fine textured with moderate permeability, and percolated water is either collected by drainage tile or reaches the groundwater. Surface vegetation has included lawns and golf courses for highly treated wastewater, pastures, and forests, but is most commonly crops, usually for animal consumption. Climatic constraints often require some winter storage of wastewater (Reed 1979). Recycling benefits include moderate groundwater recharge and the utilixation of wastewater nutrients in crop production.

In rapid infiltration wastewater is flooded, usually intermittently, into shallow basins at a rate of 20-600 feet (6-183 m) per year. Soils are usually coarse textured with high permeability, and percolated water moves to groundwater, recovery wells, or underdrains. Surface vegetation is usually absent, and climatic constraints not of concern (Reed 1979). Groundwater recharge is a recycling benefit.

Overland flow is the least commonly used land treatment system. Wastewater is applied to the top of gently sloping (2-4 percent) fields at a rate of 10-70 feet (3-21 m) per year, and moves by sheet flow down the slope to collection ditches at the base. Soils are usually fine textured with very low permeability. Surface vegetation consists of water-tolerant grasses, e.g., reed canary grass. Climatic constraints may require some winter storage of wastewater (Reed 1979). Recycling benefits may include the utilization of wastewater nutrients in harvested grass for animal forage.

Many of the examples of land application systems in the U.S. utilize wastewater treated by conventional means up to tertiary level (secondary in the case of overland flow). The objectives of these systems are usually to produce clean irrigation water (e.g., for golf course application) or highly treated water for groundwater recharge. From a wastewater treatment point of view, land application in these systems is a form of tertiary treatment or effluent "polishing," rather than true land treatment. In land treatment systems, the subject of this report, raw wastewater is given a minimum preapplication treatment or "pretreatment," e.g., by a stabilization pond, before being applied to the land, and the

land itself is the site of the major portion of the wastewater treatment.

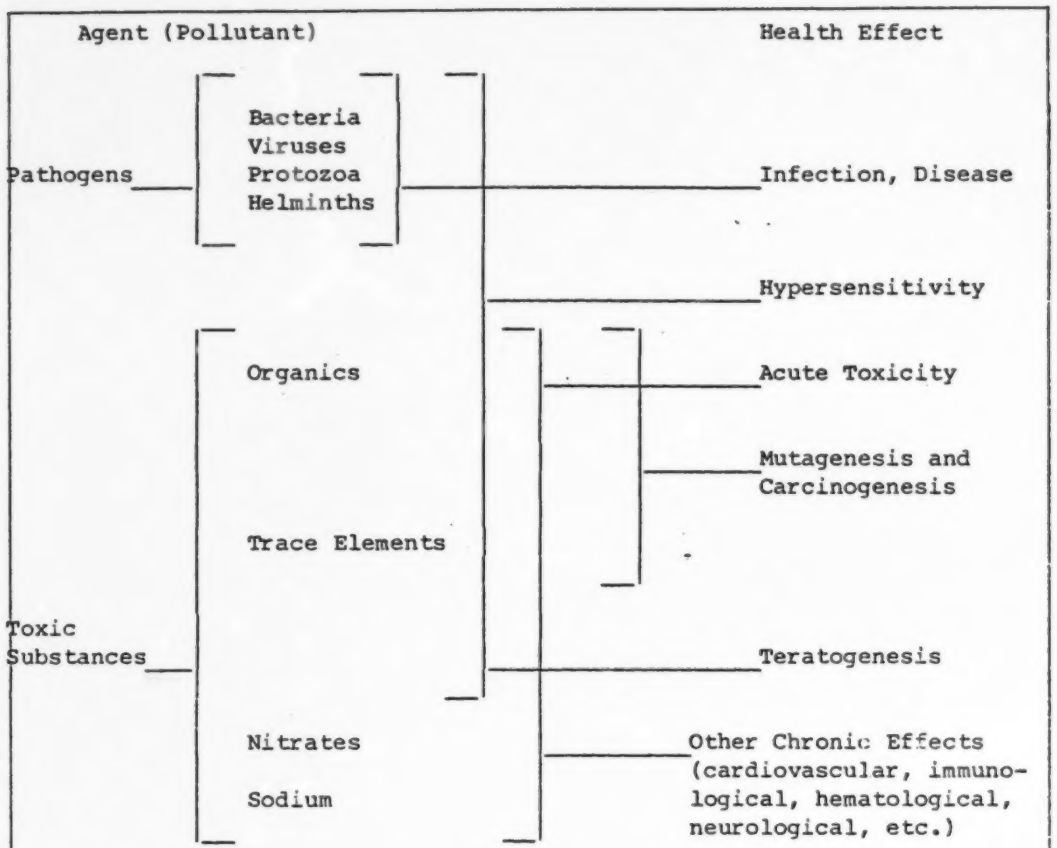
With the application to land of large volumes of minimally pretreated wastewater, it is evident that considerable potential for adverse health effects exists. These potentials have been briefly summarized by Lance and Gerba (1978) in Table 1. They identified the greatest health risks as arising from aerosols in slow rate, groundwater pollution in rapid infiltration, and surface water pollution in overland flow.

Table 1. Potential Land Treatment Health Effects

Type of land treatment system	Food contamination	Groundwater pollution	Surface Water pollution	Aerosols
Slow rate	+	+	+	++
Rapid infilitration	-	++	-	-
Overland flow	-	-	++	+

-Little or no potential problem
+Moderate potential
++Considerable potential

The agents, or pollutants, of concern from a health effects viewpoint can be divided into the two broad categories of pathogens and toxic substances. The pathogens include bacteria (e.g., Salmonella and Shigella), viruses (i.e., enteroviruses, hepatitis virus, adenoviruses, rotaviruses, and Norwalk-like agents), protozoa (e.g., Entamoeba and Giardia), and helminths (or worms, e.g., Ascaris, Trichuris, and Toxocara). The protozoa and helminths are often grouped together under the term, "parasites." The toxic substances include organics, trace elements (or heavy metals, e.g., cadmium and lead), nitrates, and sodium. Nitrates and sodium are usually not viewed as "toxic" substances, but are here so considered because of their potential hematological and long-term cardiovascular effects when present in water supplies at high levels. The major health effects of these agents are listed below:



This paper is primarily a summary of two previously published detailed reports on the health effects of land treatment (Kowal 1982, 1985), and the reader is encouraged to seek there the supporting data and arguments for the generalizations made here. In those reports the types and levels commonly found in municipal wastewater and the efficiency of preapplication treatment (usually stabilization pond) are briefly reviewed for each agent of concern. A discussion of the levels, behavior, and survival of the agent in the medium or route of potential human exposure, i.e. aerosols, surface soil and plants, subsurface soil and groundwater, and animals, follows as appropriate. For the pathogens, infective dose, risk of infection, and epidemiology are then briefly reviewed. Finally, conclusions and research needs are presented.

Bacteria

The pathogenic bacteria of major concern in wastewater are listed in Table 2. All have symptomless infections and human carrier states, and many have important nonhuman reservoirs as well.

Table 2. Pathogenic Bacteria of Major Concern in Wastewater

Name	Nonhuman reservoir
Campylobacter jejuni	Cattle, dogs, cats, poultry
Escherichia coli (pathogenic strains)	-
Leptospira spp.	Domestic and wild mammals, rats
Salmonella paratyphi (A, B, C)	-
Salmonella typhi	-
Salmonella spp.	Domestic and wild mammals, birds, turtles
Shigella sonnei, S. flexneri, S. boydii, S. dysenteriae	-
Vibrio cholerae	-
Yersinia enterocolitica, Y. pseudotuberculosis	Wild and domestic birds and mammals

The human exposure to aerosol bacteria at land treatment sites can be roughly estimated from the data at Kibbutz Tzora, Israel, where raw wastewater was sprayed, thus yielding higher bacterial levels than those found at Deer Creek, Ft. Huachuca, or Pleasanton, where treated wastewater was sprayed (see Kowal 1982). Thus, an adult male, engaged in light work, breathing at a rate of 1.2 m^3/hr, and exposed to 34 coliforms/m^3 (the Kibbutz Tzora average) at 100 m downwind from a sprinkler, would inhale approximately 41 coliforms per hour. Since the ratio of aerosolized Salmonella to coliforms is $1:10^5$ (Grunnet and Tramsen 1974) the rate of inhalation of Salmonella would be about 10^5-fold less, an extremely low rate of bacterial exposure. More recent data from Kibbutz Tzora allows a more accurate estimate of human exposure (Teltsch et al. 1980). During a period of time in 1977-78, when the wastewater total coliforms were 2.4×10^6 to 1.4×10^7/100 ml and Salmonella was 0-60/100 ml, the density of aerosol Salmonella at 40 m, the maximum distance found, was 0-0.054/m^3, with a mean of 0.014/m^3. This would result in an inhalation rate of 0.017/hr at 40 m, higher than the previous estimate, but still an extremely low rate of bacterial exposure.

The surface soil and plants of an active land treatment site are constantly heavily laden with enteric bacteria; these are the specific locations where the actual treatment of the wastewater and inactivation of the bacteria occur. (In some situations bacteria may be deposited on plants in the environs of a land treatment site, due to aerosol drift). The survival time of bacteria in surface soil and on plants is only of concern when decisions must be made on how long a period of time must be allowed after last application before permitting access to people or animals, or harvesting crops.

In view of the large number of environmental factors affecting bacterial survival in soil, it is understandable that the values found in the literature vary widely. Two useful summaries of this literature are those of Bryan (1977) and Feachem et al. (1978). The ranges given in Table 3 are extracted from these summaries, as well as other literature. "Survival" as used in this table, and throughout this report, denotes

days of detection. It should be noted that inactivation is a rate process and therefore detection depends upon the initial level of organisms, sensitivity of detection methodology, and other factors. If kept frozen, most of these bacteria would survive longer than indicated in Table 3, but this would not be a realistic soil situation.

Table 3. Survival Times of Bacteria in Soil

Coliform	4-77 days
Fecal coliform	8-55 days
Fecal streptococci	8->70 days
Leptospira	<15 days
Mycobacterium	10 days - 15 months
Salmonella paratyphi	>259 days
Salmonella typhi	1-120 days
Salmonella spp.	11->280 days
Streptococcus faecalis	26-77 days

Perhaps the largest epidemiological study of the health effects of land treatment was a retrospective study of 77 kibbutzim (agricultural cooperative settlements) in Israel practicing slow-rate land treatment with nondisinfected oxidation pond effluent, and 130 control kibbutzim (Katzenelson et al. 1976). The incidence of typhoid fever, salmonellosis, shigellosis, and infectious hepatitis was 2-4 times higher in the land-treatment kibbutzim than the controls. The study, however, did not rule out a number of pathways of infection other than aerosols, e.g., direct contact via clothing or bodies of sewage irrigation workers, and there were problems with the data reporting methods. Consequently, it is generally felt that no conclusive findings may be based on the report, and the study is currently being repeated, correcting for the deficits of the original study (Shuval and Fattal 1980). Preliminary results suggest little effect of land treatment on disease incidence.

Viruses

The human enteric viruses that may be present in wastewater are listed in Table 4 (Melnick et al. 1978, Holmes 1979). These are referred to as the enteric viruses and new members are constantly being identified. Since no viruses are normal inhabitants of the gastrointestinal tract and none of these have a major reservoir other than man (with the likely exception of rotaviruses), all may be regarded as pathogens, although most can produce asymptomatic infections.

Table 4. Human Wastewater Viruses

Enteroviruses
Poliovirus
Coxsackievirus A
Coxsackievirus B
Echovirus
New Enterovirus
Hepatitis A Virus
Rotavirus ("Duovirus," "Reovirus-like Agent")
Norwalk-Like Agents (Norwalk, Hawaii, Montgomery County, etc.)
Adenovirus
Reovirus
Papovavirus
Astrovirus
Calicivirus
Coronavirus-Like Particles

From Pleasanton, California data (Johnson et al. 1980) it can be calculated that an adult male, engaged in light work, breathing at a rate of 1.2 m^3/hour and exposed to 0.014 PFU/m^3 at 50 m downwind from a sprayer, would inhale approximately 0.13 PFU of enterovirus during an 8-hour work day. This is probably an insignificant level of exposure. However, since the recovery of enteric viruses form environmental samples is not perfectly efficient, isolation of viruses increases as more cell culture types are used, and some enteric viruses cannot yet be isolated in cell cultures, the actual exposure to enteric viruses may be as much as ten to a hundred times the reported level (Teltsch et al. 1980). Thus, it might be prudent to recommend a 100 m or 200 m minimum exposure distance of the general public to a land treatment spray source.

As is the case with bacteria, the surface soil and plants of an active land treatment site are constantly receiving enteric viruses. The survival time of viruses is primarily of concern when decisions must be made on how long a period of time must be allowed after last application before permitting access to people or animals, or harvesting crops. Another concern is that the longer viruses survive at the surface the greater opportunity they have for being desorbed and moving into the soil toward the groundwater. This is not a problem with overland flow systems, which, although 68 to 85% of the enteric viruses are deposited at the surface, little virus penetrates into the soil profile (Schaub et al. 1978, 1980).

Much of the recent literature on survival time of enteric viruses in soil is summarized in Table 5. Approximately one hundred days appears to be the maximum survival time of enteric viruses in soil, unless subject to very low temperatures, which prolong survival beyond this time. Exposure to sunlight, high temperatures, and drying greatly reduce survival times.

Table 5. Survival Time of Enteric Viruses in Soil

Virus	Soil	Moisture and temperature	Survival (days)	Reference
Enterovirus	Sandy or loamy podzol	10-20% 3-10°C	70-170	Bagdasaryan 1964
		10-20% 18-23°C	25-110	
		Air dry, 18-23°C	15-25	
Poliovirus	Sand	Moist	91	Lefler and Kott 1974
		Dry	<77	
Poliovirus	Loamy fine sand	Moist, 4°C	84 (<90% reduction)	Duboise et al. 1976
		Moist, 20°C	84 (99.999% reduction)	
Coxsackie-virus	Clay	300 mm rain-fall, -12-26°C	<161	Damgaard-Larsen et al. 1977
Poliovirus	-	-14-27°C	89-96	Tierney et al. 1977
		15-33°C	<11	
Poliovirus	Sugarcane field	Open, direct sunlight	7-9	Lau et al. 1975
		Mature sugarcane	≤60	
Poliovirus and coxsac-kievirus	Sandy loam	Saturated, 37°C	12	Yeager and O'Brien 1979
		Saturated, 4°C	≥180	
		Dried, 37°C and 4°C	<3-<30	

While viruses near the soil surface are rapidly inactivated due to the combined effects of sunlight, drying, and the antagonism of aerobic soil microorganisms, those that penetrate the aerobic zone can be expected

to survive over a more prolonged period of time. The longer they survive, the greater the chance that an event will occur to promote their penetration into groundwater (Gerba and Lance 1980).

Viruses do not regrow on foods or other environmental media, as bacteria sometimes do. Therefore, the risk of infection is completely dependent upon being exposed to an infective dose (which may be very low) in the material applied. In any event, as is the case with bacteria, it would seem prudent for humans to maintain a minimum amount of contact with an active tretament site, and to rely on the viral survival data discussed earlier for limiting the hazard from crops grown for human consumption on wastewater-amended soils.

Parasites

The protozoa and helminths (or worms) are often grouped together under the term, "parasites," although in reality all the pathogens are biologically parasites. Because of the large size of protozoan cysts and helminth eggs, compared with bacteria and viruses it is extremely unlikely that they will find their way into either aerosols or groundwater at land treatment sites, and, thus, these routes of exposure are not further considered. Little attention has been given to the presence of parasites in wastewater, and their potential for contaminating food crops in the United States, probably because of the popular impression that the prevalence of parasite infection in the U.S. is minimal (Larkin et al. 1978). However, because of the increasing recognition of parasite infections in the U.S., the return of military personnel and travelers from abroad, the level of recent immigration and food imports from countries with a high parasitic disease prevalence, and the existence of resistant stages of the organisms, a consideration of parasites is warranted.

The most common protozoa which may be found in wastewater are listed in Table 6. Of these, only three species are of major significance for transmission of disease to humans through wastewater: Entamoeba histolytica, Giardia lamblia, and Balantidium coli. Toxoplasma gondiii also causes significant human disease, but the wastewater route is probably not of importance. Eimeria spp. are often identified in human fecal samples, but are considered to be spurious parasites, entering the gastrointestinal tract from ingested fish.

Table 6. Types of Protozoa in Wastewater

Name	Protozoan Class	Nonhuman Reservoir
HUMAN PATHOGENS		
Entamoeba histolytica	Ameba	Domestic and wild mammals
Giardia lamblia	Flagellate	Beavers, dogs, sheep
Balantidium coli	Ciliate	Pigs, other mammals
Toxoplasma gondii	Sporozoan (Coccidia)	Cats
Dientamoeba fragilis	Ameba	
Isospora belli	Sporozoan (Coccidia)	
I hominis	Sporozoan (Coccidia)	
HUMAN COMMENSALS		
Endolimax nana	Ameba	
Entamoeba coli	Ameba	
Iodamoeba butschlii	Ameba	
ANIMAL PATHOGENS		
Eimeria spp.	Sporozoan (Coccidia)	Fish, birds, mammals
Entamoeba spp.	Ameba	Rodents, etc.
Giardia spp.	Flagellate	Dogs, cats, wild mammals
Isospora spp.	Sporozoan (Coccidia)	Dogs, cats

The pathogenic helminths whose eggs are of major concern in wastewater are listed in Table 7. They are taxomomically divided into the nematodes, or roundworms, and cestodes, or tapeworms. The trematodes, or flukes, are not included since they require aquatic conditions and intermediate hosts, usually snails, to complete their life cycles, and thus are unlikely to be of concern at land treatment sites. Several of the human pathogens listed in Table 7, e.g., Toxocara spp., are actually animal parasites, rather than human parasites, infesting man only incidentally, and not completing their life cycle in man.

Table 7. Pathogenic Helminths of Major Concern in Wastewater

Pathogen	Common Name	Disease	Nonhuman Reservoir
NEMATODES (Roundworms)			
Enterobius vermicularis	Pinworm	Enterobiasis	
Ascaris lumbricoides	Roundworm	Ascariasis	
A. suum	Swine roundworm	Ascariasis	Pig*
Trichuris trichiura	Whipworm	Trichuriasis	
Necator americanus	Hookworm	Necatoriasis	
Ancylostoma duodenale	Hookworm	Ancylostomiasis	
A. braziliense	Cat hookworm	Cutaneous larva migrans	Cat, dog*
A. caninum	Dog hookworm	Cutaneous larva migrans	Dog*
Strongyloides stercoralis	Threadworm	Strongyloidiasis	Dog
Toxocara canis	Dog roundworm	Visceral larva migrans	Dog*
T. cati	Cat roundworm	Visceral larva migrans	Cat*
CESTODES (Tapeworms)			
Taenia saginata**	Beef tapeworm	Taeniasis	
T. solium	Pork tapeworm	Taeniasis, Cysticercosis	
Hymenolepis nana	Dwarf tapeworm	Taeniasis	Rat, mouse
Echinococcus granulosus	Dog tapeworm	Unilocular hydatid disease	Dog*
E. multilocularis		Alveolar hydatid disease	Dog, fox, cat*

*Definitive host; man only incidentally infested.
**Eggs not infective for man.

Protozoa cysts are highly sensitive to drying. Rudolfs et al. (1951) have reported survival times for Entamoeba histolytica of 18-24 hours in dry soil and 42-72 hours in moist soil. Somewhat longer times, i.e., 8-10 days, have been reported by Beaver and Deschamps (1949) in damp loam and sand at 28-34°C.

Helminth eggs and larvae, in contrast to protozoan cysts, live for long periods of time when applied to the land, probably because soil is the transmission medium for which they have evolved, while protozoa have evolved toward water transmission. Thus, under favorable conditions of moisture. temperature, and sunlight, Ascaris, Trichuris, and Toxocara can remain viable and infective for several years (Little 1980). Hookworms can survive up to 6 months (Feachem et al. 1978), and Taenia a few days to seven months (Babayeva 1966); other helminths survive for shorter periods.

Single eggs of helminths are infectious to man, although, since the symptoms of helminth infections are dose-related, many light infections are asymptomatic. However, Ascaris infection may sensitize individuals so that the passage of a single larval stage through the lungs may result in allergic symptoms, i.e., asthma and urticaria (Muller 1953).

Because of the low infective doses of helminth eggs, and their longevity, it would be prudent for humans to maintain a minimum amount of contact with an active or inactive land treatment site, unless the wastewater has been pretreated to remove helminths.

Organics

The potential health effects of toxic organic compounds are myriad. Systems affected range from the dermatological to the nervous to the subcellular, and effects produced range from rash to motor dysfunction to cancer. The degree of toxicity of organic compounds varies widely, from essentially harmless (e.g., most carbohydrates) to moderately toxic (e.g., most alcohols) to extremely toxic (e.g., aflatoxins).

A glance at the current edition of The Merck Index will reveal that the number of organic compounds described thus far is almost unfathomable. Nearly any of these may appear in wastewater, depending upon its sources. Thus, the discussion below must be perforce rather general, and the presence of any particular toxic organic in high concentration in the wastewater may require a site-specific evaluation of potential health effects.

The major contributors of toxic organics to municipal wastewaters are usually assumed to be industrial discharges. However, household wastewater discharge may represent an important contributor since many consumer products in daily use contain toxic substances. A recent study (Hathaway 1980) identified consumer products containing toxic compounds on EPA's list of 129 priority pollutants, which may eventually end up in wastewater. The most frequently used products are cleaning agents and cosmetics, containing solvents and heavy metals as main ingredients. Next are deodorizers and disinfectants, containing naphthalene, phenol, and chlorophenols. Discarded into wastewater infrequently, but in large volumes, are pesticides, laundry products, paint products, polishes, and preservatives. The organic priority pollutants most frequently used and discharged into domestic wastewater were predicted to be the following:

benzene
phenol
2,4,6-trichlorophenol
2-chlorophenol
1,2-dichlorobenzene
1,4-dichlorobenzene
1,1,1-trichloroethane
naphthalene
toluene
diethylphthalate
dimethylphthalate
trichloroethylene
aldrin
dieldrin

Because of the difficulty of analysis of complex mixtures, it has only recently been possible to measure the actual levels of organics in wastewater using advanced methods of extraction, gas and other chromatography, mass spectrometry, and computer analysis. The U. S. Environmental Protection Agency has sponsored two extensive surveys of the types and levels of priority pollutants in municipal wastewaters, which, of course, result from both domestic and industrial discharges. The first (DeWalle et al. 1981), supported by the Municipal Environmental Research Laboratory in Cincinnati, covered 25 cities located throughout the United States, and the second (Burns & Roe 1982), supported by the Effluent Guidelines Division in Washington, D. C., covered 40 cities.

In the 25-city survey (DeWalle et al. 1981) most of the 24-hour composite samples of raw wastewaters contained a total of less than 1 mg/l of priority organics, and the numbers of compounds detected clustered between 20 and 50. In the 40-city survey (Burns & Roe 1982) six days of 24-hour sampling was completed, and the samples from 20 cities were analyzed. The priority organics detected in at least 50% of the samples analyzed in either survey are listed in Table 8.

Comparison of the results of the two surveys with the list of organic priority pollutants most likely to be discharged into domestic wastewater, reveals considerable overlap, and gives one some confidence that these two studies have yielded a reasonable characterization of the priority organics in municipal wastewater, at least of those identifiable by modern methods. The broad range of concentrations detected among the samples, however, suggests that wastewater applied to land should be regularly monitored for toxic organics. This measure is emphasized by the occasional discharge of toxic substances into municipal wastewater systems with resulting medical effects in treatment plant workers, such as the recent hexachlorocyclopentadiene episode in Louisville, Kentucky (Kominsky et al. 1980).

Table 8. Most Frequently Detected Priority Organics in Raw Municipal Wastewater (detection frequency, %)

Compound	DeWalle et al. 1981	Burns & Roe 1982
Phenol	94	79
1,1,1-Trichloroethane	94	85
Trichloroethylene	94	90
Tetrachloroethylene	94	95
Ethylbenzene	94	80
Trichloromethane (Chloroform)	94	91
Diethylphthalate	91	53
Di-n-butylphthalate	91	64
Toluene	90	96
Dichloromethane	90	92
Bis(2-ethylhexyl)phthalate	89	92
Naphthalene	86	49
1,4-Dichlorobenzene	83	17
Phenanthrene	83	20
Benzene	79	61
Heptachlor	77	5
Butylbenzylphthalate	77	57
BHC-G (Lindane)	71	26
1,2-Dichlorobenzene	69	23
Dimethylphthalate	66	11
BHC-D	63	3
Dieldrin	63	1
1,3-Dichlorobenzene	60	7
BHC-A	60	8
DDT	60	<1
Di-n-octylphthalate	57	7
1,1-Dichloroethane	55	31
1,2-Dichloroethane	55	15
DDD	54	1
Anthracene	51	18
Aldrin	51	-
Endosulfan-B	51	-
1,2-Trans-dichloroethylene	20	62

In view of the multitudinous variety of organic compounds existing, it is difficult to generalize about their biodegradation in soil. It appears, however, that most organics do become microbially decomposed in

the soil, at least to some extent. This is especially true of naturally-occurring compounds, or those resembling them, because of the eons of evolution that have developed microbial enzyme systems to do the job. The more structually complex the molecule is, e.g., condensed rings or dense branching, and more halogenated it is, the more difficult is biodegradation.

From existing data it is evident that toxic organics can be transported to groundwater below land treatment sites, although the degree can be controlled by the level of preapplication treatment and application rate as well as choice of effluent and site characteristics. This certainly is cause for concern, but it should be kept in mind that groundwater is not the pristine substance it was once thought to be (Burmaster 1982). The synthetic organic compounds most commonly found in groundwater in the U. S., deriving primarily from industrial wastes, are (Environmental Health Letter 21(6):7, 1982):

trichloroethylene	benzene
tetrachloroethylene	chlorobenzene
carbon tetrachloride	dichlorobenzene
1,1,1-trichloroethane	trichlorobenzene
1,2-dichloroethane	1,1-dichloroethylene
vinyl chloride	cis-1,2-dichloroethylene
methylene chloride	trans-1,2-dichloroethylene

Trace Elements

The trace elements (including the "heavy metals") in wastewater of public health concern, i.e., those for which primary drinking water standards (USEPA 1977) exist (but excluding silver since its effect is largely cosmetic), are:

	Primary Drinking Water Standard (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.010
Chromium (Cr)	0.05
Lead (Pb)	0.05
Mercury (Hg)	0.002
Selenium (Se)	0.01

Of these, cadmium, lead, and mercury are usually regarded as of most concern, and barium of minor concern. Chromium and selenium are essential elements in man; arsenic and cadmium have been shown to be essential to experimental animals and, thus, may be essential to man as well (National Research Council 1980). Secondary drinking water standards (USEPA 1979), i.e., those related to aesthetic quality, also exist for copper, iron, manganese, and zinc. These latter elements, as well as all other trace elements, are toxic if ingested or inhaled at high levels for long periods (Underwood 1977), but this fact does not warrant considering them in the land treatment context, where low levels are expected.

Limits for the maximum cumulative application of trace elements to

agricultural land have been recommended by various governmental agencies, for the protection of public health and the prevention of phytotoxicity. These have almost invariably been proposed in the context of the land application of sludge, but should be just as valid for land treatment of wastewater, at least in the slow rate mode. Limits for rapid infiltration and overland flow could be less restrictive because of the lack of production of crops for human consumption and the greater depth of soil involved in treatment (in the former case). These limits have been used, together with typical wastewater levels of trace elements, by Page and Chang (1981) to predict the useful life of a typical land treatment site where crops are grown for human consumption. The results appear in Table 9. It is evident that cadmium, with a 17-67 year limit, is the element most likely to restrict the use of wastewater for irrigation of crops for human consumption. In the case of crops not for human consumption, other elements may be limiting--in particular molybdenum because of its toxicity to livestock, and nickel because of its phytotoxicity. These latter elements yield limits of 47-48 years in Page and Chang's analysis.

Table 9. Annual Input of Trace Elements and Years of Land Treatment Required to Exceed Recommended Cumulative Input Limits (modified from Page and Chang 1981)

Element	Concentration in Wastewater (mg/l)	Annual Input[1] (kg/ha)	Recommended Cumulative Input Limits (kg/ha)		Years Required to Exceed Limits	
			USA[2]	UK[3]	USA	UK
Arsenic	0.005	0.075	-	10	-	133
Cadmium	0.02	0.3	5/10/20[4]	5	17/33/67[4]	17
Chromium	0.05	0.75	-	1000	-	1333
Lead	0.2[5]	3.0	800	1000	267	333
Mercury	0.0009	0.014	-	2	-	143
Selenium	0.005	0.075	-	5	-	67

[1]Assuming an annual application rate of 1.5 m.
[2]USEPA, USFDA, and USDA 1981.
[3]National Water Council 1977.
[4]For soils with cation exchange capacities of <5, 5-15, and >15 meq/100g, respectively, and soil pH >6.5. If soil pH <6.5, first figure holds.
[5]Raised over the value presented in Page and Chang (1981), to reflect recent data.

Nitrates

Inorganic nitrogen is normally quite innocuous from a human health point of view, although high ammonia levels can present an aesthetic problem. The major health concern is that infants, less than about three months of age and consuming large quantities of high-nitrate drinking water through prepared formula, have a high risk of developing methemoglobinemia. The incompletely developed capacity to secrete gastric acid in the infant allows the gastric pH to rise sufficiently to encourage the growth of bacteria which reduce nitrate to nitrite in the upper gastrointestinal tract. The nitrite is absorbed into the bloodstream, and oxidizes the ferrous iron in hemoglobin to the ferric state, in which form it is incapable of carrying oxygen. Fetal hemoglobin (Hb F), 50-89% of total hemoglobin at birth, is particularly susceptible to this transformation. Methemoglobin is normally present in the erythrocytes of adults, at a concentration of about 1% of total hemoglobin, being formed by numerous agents, but kept to a low level by the methemoglobin reductase enzyme system. This enzyme system is normally not completely developed in young infants. At a methemoglobin concentration of about 5-10% of total hemoglobin the body's oxygen deficit results in clinically-detectable cyanosis. As a result of epidemiological and clinical studies (Shuval & Gruener 1977, Craun et al. 1981, Fraser and Chilvers 1981) a primary drinking water standard of 10 mg/l of nitrate-nitrogen (i.e., nitrate expressed as N) has been established (USEPA 1977) to prevent this condition from developing.

Besides methemoglobinemia, there is also some concern about nitrates resulting in the formation of carcinogenic N-nitroso compounds in the gut, but this phenomenon probably involves higher concentrations than the 10 mg/l water standard (Fraser et al. 1980, Fraser and Childers 1981).

The relevance of land treatment, of course, centers on the possibility of highly soluble nitrates reaching groundwater which may be used as a potable water supply.

Comparison with Conventional Systems

The comparison of the potential health effects of land treatment, caused by both pathogens and toxic substances, with those of conventional treatment is necessarily highly subjective. Nevertheless, there are suggestions that land treatment is at least equally protective of public health as conventional treatment.

A comparison of bacterial aerosol levels at conventional activated sludge plants and a spray irrigation land treatment site has been performed by Clarke et al. (1978), to evaluate relative human exposure levels at these two types of facilities. They concluded that airborne bacterial levels, as measured by fecal coliforms, appear to be higher at the activated sludge plants than at the spray irrigation facility.

A broad comparison of health risks between activated sludge treatment and slow-rate land treatment has been performed by Crites and Uiga (1979, Uiga et al. 1978). The comparison assumed: (1) A flow of 3 M gal/day of domestic wastewater. (2) Activated sludge treatment is followed by disinfection and surface water discharge. (3) Land treatment is preceded by aerated lagoon preapplication treatment and storage, and followed by percolate water recovery using underdrains and surface water discharge,

with no disinfection. They arrived at the following conclusions comparing the two systems:

1. If maintained and operated properly, both conventional and land treatment systems provide a large measure of safety for public health. Slow-rate land treatment offers greater protection against parasites, viruses, trace organics, halogenated organics, trace elements, and nitrate.

2. Since adequate removal of parasite eggs and cysts require such measures as filtration or long detention times in ponds or storage lagoons, land treatment offers greater protection from health risks.

3. Land treatment systems, especially those with ponds and storage lagoons, remove viruses to a higher degree than do conventional treatment and disinfection systems.

4. Land treatment systems are less susceptible to failure or upsets than conventional systems, especially for small systems.

In an overview of existing land treatment systems, Iskandar (1978) concluded that "the potential health hazards from land treatment are no greater and probably less than those from conventional treatment. . . . Although land treatment, like all known waste treatment systems, has potential health hazards associated with it, these risks can be kept to a minimum." The risks associated with alternative systems of wastewater treatment and disposal, conventional as well as land treatment, should be defined and compared. He considered it to be rather odd that land treatment instills so much more public fear than conventional treatment.

Recent Epidemiological Studies

Two extensive prospective epidemiological studies of the effect of land application of wastewater on infectious disease in the exposed population have recently been completed in Lubbock, Texas (Camann et al. 1985) and in Israel (Shuval et al. 1985). This section is extracted from the cited draft final reports for these two projects, and thus is subject to future (probably minimal) modification.

The Lubbock Infection Surveillance Study (LISS) was conducted to monitor infections and acute illness in the primarily rural community surrounding the Lubbock Land Treatment (Demonstration) System (LLTS) at the Hancock farm near Wilson, Texas. The LISS objective was to identify possible adverse effects on human health from slow-rate (sprinkler) land application of wastewater which contained potentially pathogenic microorganisms.

An epidemiological analytic prospective cohort study of 478 area residents and Hancock farm workers was maintained during the first 20 months of operation of the LLTS (February 1982-October 1983) and during the 20-month period immediately preceding LLTS operation (June 1980-January 1982). Blood samples collected semiannually were analyzed for antibody titers to 14 enteroviruses, 3 adenoviruses, 2 reoviruses, rotavirus, Norwalk virus, hepatitis A, Legionella, Entamoeba histolytica, and

influenza A. Routine fecal specimens were collected regularly to isolate enteric viruses and overt and opportunistic bacterial pathogens. Electron microscopic examination was performed to detect a variety of other virus-like particles. Tuberculin skin tests were administered annually to detect non-tuberculosis mycobacterial infections. Illness information was provided by study participants on a weekly basis. Concentrations of microorganisms also were measured in the wastewater, wastewater aerosol, and drinking water. Dispersion modeling, participant activity diaries, and a weekly log of extensive wastewater contact were used to calculate an aerosol exposure index of relative cummulative exposure of each participant to the wastewater aerosol within each of the four major irrigation seasons.

Very high levels of bacteria and enteric viruses were present in the sprayed wastewater obtained via pipeline directly from the Lubbock sewage treatment plant. Enteroviruses were consistently found in the wastewater aerosol in 1982.

Participants in the high and low exposure groups were generally well balanced with regard to age, gender, previous titer, and time spent in Lubbock. However, aerosol exposure was largely confounded with patronage of a local restaurant and use of evaporative cooler air conditioners.

Disease surveillance did not disclose any obvious connection between the self-reporting of acute illness and degree of aerosol exposure.

Whenever a sufficient number of infections was observed during an irrigation season, this infection episode was analyzed by four different methods: confirmatory statistical analysis, exploratory logistic regression analysis, confidence intervals of incidence density ratios, and risk ratio scoring. The association of infection status with wastewater aerosol exposure and other relevant factors was investigated.

Comparisons of crude seroconversion incidence densities indicated that some excess risk of viral infection (risk ratio of 1.5 to 1.8) appeared to be associated with level of aerosol exposure. A symmetric risk ratio scoring approach provided evidence of a dose-related stable assocation ($p=0.002$) between the infection events in the observed episodes of infection and aerosol exposure. More than the expected number of statistically significant associations of the presence of infection with wastewater aerosol exposure were found in the confirmatory analysis of independent infection episodes using Fisher's exact test. Thus, three different statistical approaches provided similar evidence that the rate of viral infections was slightly higher among members of the study population who had a high degree of aerosol exposure.

In the episode of poliovirus 1 seroconversion in spring 1982, some of the infections were probably caused by wastewater aerosol exposure because a strong association existed and no alternative explanation could be identified. Three distinct factors (poliovirus immunization in spring 1982, low polio 1 antibody titer in January 1982, and a high degree of aerosol exposure) were independently associated with the poliovirus 1 seroconversion and each appears to have been responsible for some of the poliovirus 1 infections. Weak evidence of association was found between aerosol exposure and infection by other enteric viruses (specific coxsackie B viruses and echoviruses) which were simultaneously recovered from the wastewater during the summer irrigation season of 1982. However, it could not be determined whether aerosol exposure or identified alternative explanations were the actual risk factor(s) in these enteric viral infec-

tions. The association of viral infections with aerosol exposure shows a dose effect, since the study population was exposed to more enteroviruses via the wastewater aerosol in 1982 than in 1983.

In summary, a general association existed between exposure to irrigation wastewater and new infections. A viral dose-response relationship was observed over the four irrigation seasons, since the aerosol exposure-associated episodes of viral infection occurred primarily in 1982 during the irrigation seasons of greater enterovirus aerosol exposure. Some poliovirus 1 seroconversions during the spring of 1982 were probably related to wastewater aerosol exposure. However, even during 1982, the strength of association remained weak and frequently was not stable. Wastewater of poor quality comprised much of the irrigation water in 1982. Of the many infection episodes observed in the study population, few appear to have been associated with wastewater aerosol exposure, and none resulted in serious illness.

In Israel a prospective epidemiological study of possible disease transmission associated with land application of wastewater was carried out in kibbutzim (collective agricultural settlements) between March 1980 and February 1982 (Shuval et al. 1985). Medical data was collected directly from the patients' files and daily logs of physicians and nurses at each kibbutz clinic. The morbidity data was collected in 29 kibbutzim. The study population was 15,605, and 104,298 clinic visits were recorded in both nurses and physicians records.

No significant excess of enteric disease rates was found in any age group, including the 0-5 years old age group, in kibbutzim exposed to wastewater aerosols (category A) as compared with kibbutzim using wastewater - but not exposed to aerosols (category B), or in kibbutzim of the control group - not exposed to wastewater in any form (category C).

Children of the 0-5 years old age group of all water contact workers (including wastewater contact) in category A had a statistically significant excess of enteric disease as compared with children of the same age group in categories B and C. This excess was not found among children of wastewater contact workers; however their number was too small for effective analysis. Notwithstanding the suggestive evidence supporting direct person to person contact infection of children of water contact workers, it is difficult to draw any firm conclusions from these findings at this stage.

The serological portion of the study proved to be a particularly sensitive technique, since it surmounted problems of nonuniform clinic reporting and allowed the detection of numerous subclinical cases that did not appear in the morbidity data. This study, which encompassed a sample of 1810 persons in 29 kibbutzim, confirmed, in general, the findings of the morbidity study. Of 8 enteroviruses tested, including infectious hepatitis A, no excess in antibody levels was found in the population of 7 kibbutzim exposed to wastewater as compared to controls. However, an excess of ECHO 4 antibodies in the 0-5 age group was detected in kibbutz subcategory A1, exposed to sprinkler irrigation with effluent from neighboring towns, for 1980. this virus was not present in the population for many years prior to the 1980 epidemic, resulting in a particularly high number of susceptibles in younger age groups. This finding suggests that under unusual conditions, such as in an epidemic of an enteric virus for which there is low immunity among the population, transmission and infection by aerosolized wastewater may occur.

In the study, little or no health risks (i.e. excess disease) associated with wastewater irrigation were detected, despite the poor quality of effluent used. Apparently the dominant mode of transmission of enteric disease in the study population was by direct person to person contact or by food-borne contact. The possibility of aerosol transmission of viruses under uusual circumstances is supported by the circumstantial evidence provided by the serological study.

Recent International Views

In July of 1985 a meeting was convened by The World Bank and the World Health Organization in Engelberg, Switzerland, to discuss the health aspects of excreta and wastewater use in agriculture and aquaculture (IRCWD 1985). The meeting was hosted by the International Reference Centre for Wastes Disposal, and included environmental engineers, epidemiologists, and social scientists.

The meeting reviewed the progress that had been made in understanding the health effects of human waste reuse since the publication of the World Health Organization's widely accepted report published in 1973, and entitled "Reuse of Effluents: Methods of Wastewater Treatment and Health Safeguards," WHO Technical Report Series No. 517. The concensus of the meeting was that many standards for human waste reuse, including those recommended in WHO Technical Report No. 517, are unjustifiably restrictive and not supported by currently available epidemiologic evidence. Thus, the meeting recommended that WHO initiate revision of its Technical Report No. 517 in the nearest possible future. It recommended that other interested international agencies such as The World Bank, FAO, and UNEP participate in this revision or be otherwise consulted in an appropriate manner.

The meeting's recommendations for the microbiological quality of treated wastewaters to be used for agricultural irrigation are reproduced in Table 10. These recommendations were considered to be technically feasible and in accord with the best currently available epidemiologic evidence. They introduce for the first time a guideline for the helminthic quality of treated wastewater. The quality guideline for restricted irrigation (trees, industrial and fodder crops, fruit trees, and pasture) implies a high removal (>99 per cent) of helminth eggs, and its purpose is to protect the health of agricultural laborers. It was thought to be readily achievable through a variety of treatment technologies but, in many cases, the most appropriate treatment method will be a two-cell waste stabilization pond system (either a 1-day anaerobic pond followed by a 5-day facultative pond, or two 5-day facultative ponds).

The guidelines for unrestricted irrigation (edible crops, sports fields, and public parks) comprise the same requirement for helminth eggs and a maximum geometric mean concentration of 1000 fecal coliforms per 100 ml. The latter recommendation implies a very high level of removal of fecal bacteria (5-6 log units or >99.999 per cent). Its purpose is to protect the health of the consumers of crops (principally vegetables). This was thought to be readily achievable in a properly designed series of waste stabilization ponds. For the range of temperatures normally encountered in tropical and subtropical areas, a series of four 5-day ponds will normally produce an effluent of this required quality. Such a series of ponds would also produce a stable and aesthetically acceptable

effluent. The irrigation of sports fields and public parks, especially hotel lawns, may require a more stringent standard as the health risks may be greater to those who come into contact with recently irrigated grass.

Table 10. Tentative Microbiological Quality Guidelines for Treated Wastewater Reuse in Agricultural Irrigation[1]

Reuse Process	Intestinal nematodes[2] (geometric mean no. of viable eggs per litre)	Fecal coliforms (geometric mean no. per 100 ml)
Restricted irrigation[3]		
Irrigation of trees, industrial crops, fodder crops, fruit trees[4], and pasture[5]	< 1	not applicable
Unrestricted irrigation		
Irrigation of edible crops, sports fields, and public parks[6]	< 1	< 1000[7]

[1]In specific cases, local epidemiological, sociocultural, and hydrogeological factors should be taken into account, and these guidelines modified accordingly.
[2]Ascaris, Trichuris, and hookworms
[3]A minimum degree of treatment equivalent to at least a 1-day anaerobic pond followed by a 5-day facultative pond or its equivalent is required in all cases.
[4]Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground.
[5]Irrigation should cease two weeks before animals are allowed to graze.
[6]Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas.
[7]When edible crops are always consumed well-cooked, this recommendation may be less stringent.

Conclusions

Types and Levels in Wastewater

The types and levels in wastewater of most pathogens are fairly well understood, with the exception of viruses. Since only a small fraction of the total viruses in wastewater and other environmental samples may actually be detected, the development of methods to recover and detect viruses continues to be a research need. The occurrence of viruses in an environmental setting should probably be based on viral tests rather than bacterial indicators since failures in this indicator system have been reported.

The tremendous number of organic compounds possibly present in wastewater, together with their myriad health effects and poorly understood behavior in the environment, represent a considerable potential for adverse health effects. Most of these can probably be prevented by simple design and monitoring measures; this, of course, would not be true in the case of discharges containing high levels of particular chemicals.

It seems reasonable to conclude that cadmium is the only trace element likely to be of health concern to humans as a result of land treatment of wastewater, with the exposure being through food plants or organ meats.

Preapplication Treatment

The level of preapplicaton treatment required for the protection of public health may be as little as properly-designed sedimentation at land treatment sites with limited public access, where crops are protected by appropriate crop choice and waiting periods, and groundwater is protected by appropriate hydrological studies and application rate selection. Where protection of groundwater cannot be assured, wastewater stabilization ponds should be considered for virus removal, but further investigations into the survival of viruses in these ponds is an important research need, as is that of protozoan cysts. Because of potential contamination of crops and infection of animals, slow-rate and overland-flow systems should have high removal rate of helminth eggs. These relatively simple pretreatment requirements would be appropriate for many land treatment systems in the U. S., e.g., for many slow-rate sites where crops for animal feed are grown.

Preapplication treatment by storage lagoons may remove considerable quantities of organics, but cannot be relied upon to efficiently remove all toxic organics, particularly since most pretreatment design questions center on inactivation of pathogens.

The recommendations made in the paragraphs below assume a minimum level of preapplication treatment, i.e., properly-designed sedimentation. In situations with greater public access (e.g., renovated water reuse on golf courses), shorter waiting periods before grazing or harvest of crops (e.g., agriculture in arid areas), or threat of groundwater contamination (e.g., shallow water table used as a drinking water source), more extensive preapplication treatment may be required. This treatment may consist of wastewater stabilization ponds, conventional treatment unit processes, or even disinfection. The exact degree of pretreatment required for these situations is site-specific, and recommendations should be determined separately for each system (Lance and Gerba 1978).

Aerosols

Because of the potential exposure to aerosolized viruses at land treatment sites, it would be prudent to limit public access to 100-200 m from a spray source, unless the effluent has been disinfected. At this distance bacteria are also unlikely to pose significant risk. Human exposure to pathogenic protozoa or helminth eggs through aerosols is extremely unlikely.

Suppression of aerosol formation by the use of downward-directed, low-pressure nozzles, ridge-and-furrow irrigation, or drip irrigation is

recommended where these application techniques are feasible.

Although removal rates of organics from wastewater by aerosolization and volatilization are high, exposure through this route is unlikely to present any significant health effect.

Surface Soil and Plants

The survival times of pathogens on soil and plants are summarized in Table 11 (after Feachem et al. 1978). Since pathogens survive for a much longer time on soil than plants, the recommended waiting periods before harvest are based upon probable contamination with soil.

Aerial crops with little chance for contact with soil should not be harvested for human consumption for at least one month after the last wastewater application; subsurface and low-growing crops for human consumption should not be grown at a land treatment site for at least six months after last application. These waiting periods need not apply to the growth of crops for animal feed, however.

An important research need is the effect of drying of the soil between wastewater applications on the survival of surface-soil viruses.

The levels of toxic organics likely to be present in soils at land treatment sites will probably result in extremely low levels in aboveground portions of plants, but levels in roots, tubers, and bulbs may present a health hazard.

The potential increase in cadmium levels in human food due to land treatment or irrigation is still an unsettled question. It is clear, however, that increased cadmium in the soil results in increased cadmium in the plants grown in that soil, the degree of increase being a function of cadmium amendment, plant species and cultivar, soil pH, organic matter, and time since application (Ryan et al. 1982). The degree of risk to man, of course, is dependent upon the amount of the food supply affected and the diet selection of the individual. Present levels of total dietary intake of cadmium for most people appear to be fairly safe. However, in view of human variability in sensitivity and the variability in food supply, these levels probably should not be allowed to rise greatly.

TABLE 11. Survival times of Pathogens on Soil and Plants

	Soil		Plants	
Pathogen	Absolute Maximum	Common Maximum	Absolute Maximum	Common Maximum
Bacteria	1 year	2 months	6 months	1 month
Viruses	6 months	3 months	2 months	1 month
Protozoa	10 days	2 days	5 days	2 days
Helminths	7 years	2 years	5 months	1 month

The most significant research need in the area of trace elements probably continues to be the development of an understanding of the factors controlling the uptake of trace elements by plant crops at land

treatment sites, and their entry into the human food supply.

Movement in Soil and Groundwater

Properly designed slow-rate land treatment systems pose little threat of bacterial or viral contamination of groundwater. Considerable threat of bacterial contamination exists, however, at rapid-infiltration sites where the water table is shallow, particularly if the soil is porous. The survival of bacteria in groundwater, once they get there, is poorly understood, and is an important research need.

Likewise, considerable potential for viral contamination of groundwater exists at rapid-infiltration sites, and appropriate preapplication treatment or management techniques should be instituted, e.g., intermittent application of wastewater. Until then, groundwater drawn for use as potable water supplies should be disinfected. The factors controlling the migration of viruses in soils, and the survival of viruses in groundwater, are poorly understood, and are significant research needs.

Human exposure to pathogenic protozoa or helminths through groundwater is extremely unlikely.

Toxic organics can enter the groundwater, particularly at rapid infiltration sites, and the application and soil factors controlling this transport, together with the factors governing their movement and decomposition within groundwater, are significant research needs.

Groundwater is unlikely to represent a significant trace element threat except at rapid infiltration sites.

Land treatment systems, particularly rapid-infiltration, threaten to raise the nitrate concentration in their underlying groundwater above the drinking water standard of 10 mg/l as N. This can be prevented, however, by proper siting and management practice, e.g., using high C:N ratio wastewater, matching loading rate to crop uptake (for slow-rate systems), and optimizing the flooding-drying regime. These management practices and the agronomic factors controlling the entrance of nitrates into groundwater are important research needs.

Increased groundwater sodium concentrations beneath land treatment sites should be kept in mind as a possible future health concern.

Animals

There appears to be little danger of bacterial, viral, or protozoan disease to animals grazing at land treatment sites if grazing does not resume until four weeks after last application. However, the role of animals in transmitting human viral diseases at land application sites is poorly known, and is a research need. Removal of helminth eggs during preapplication treatment should eliminate the potential of disease from those long-lived parasites. The feeding of land-treatment-site-grown plants to animals is unlikely to pose a health problem, but grazing animals may accumulate significant levels of toxic organics. The issue of accumulation of organics from the soil by plants and animals (particularly into milk) is poorly understood, and more research is required.

Infective Dose, Risk of Infection, Epidemiology

Because of the possibility of picking up an infection, it would be

wise for humans to maintain a minimum amount of contact with an active land treatment site. The comparison of the respiratory infective dose of enteric viruses with the oral infective dose is a significant research need.

Epidemiological studies to date suggest little effect of land treatment on disease incidence. However, they do indicate that nonsymptomatic viral infections can be transmitted by aerosols. Nevertheless, there appears to be a consensus developing to make guidelines for the application of wastewater to land less restrictive.

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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